EDITORIAL

‘Alien’ Species, ‘Pertinacious Weeds’ and the ‘Ideal Weed’ – Revisited

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Landmark Events in the evolution of *Weed Science*

A sound knowledge of the history of *Weed Science* – is essential for us weed scientists to adapt to emerging challenges and paradigm shifts in our dealings with weeds. It is helpful to know how we got to where we are in *Weed Science*.

This knowledge of history should include a good grasp of reflections and ideas of our founders, which defined the pathway for the discipline to evolve as an indispensable scientific endeavour it has now become. As in any discipline, there were seminal events, pivotal moments and key individuals whose efforts laid our foundations and pioneered a shared interest. In this Editorial, I wish to revisit a few of these.

Many of today’s ecological and environmental issues are contentious, socially divisive, and appear intractable. They are, however, typical of complex issues that ecologists and natural resource managers have to deal with everyday and into the foreseeable future. Weed scientists are also continually exposed to complex issues related to pioneering species, or colonizing taxa (in other words, ‘weeds’) as they grapple with negative effects vs. positive effects of these extraordinary group of plants.

We must educate ourselves to interact and deal with weeds better while aspiring to protect our environment, biological diversity, and agricultural production. It is the responsibility of every weed scientist to study weeds to obtain meaningful information and provide critical analyses of weed-related issues to help inform and educate the public.

In this regard, Robert Zimdahl has elaborated on various moral, ethical, and contentious technical issues that have risen within the broader disciplines of agriculture and Weed Science, published in this journal (Zimdahl, 2019) and elsewhere (Zimdahl, 2010a; 2012; 2018). These analyses and viewpoints should be essential readings for the next generation of weed scientists.

Weedy colonizer species do pose significant challenges to some human endeavours, although not all such taxa are bad all the time, in all situations. Dealing with organisms that have colonizing capabilities is simply one element in our complex relationship with Nature.

As *Weed Science* took shape in the 1950s, our founding fathers, too, confronted challenges and issues, especially in understanding the ecological roles of pioneering species as part of plant succession. In the efforts to understand the roles of weedy species in nature and how they respond to human-caused disturbances, the direction of the discipline was almost certainly defined by growing concerns over the overuse of herbicides in the 1950s decade (Harper, 1956; 1957).

It is also true that *Weed Science* not only first emerged as a science, but also has continued to date under the dominating influence of discoveries and applications of a vast number of chemical herbicides.

Due to the strong marketing campaigns by herbicide manufacturers in the early days (1960s through 1990s), *Weed Science might have been properly called Herbicide Science* (Thill *et al.*, 1991). Lamenting on this negative perception, Donald Wyse (1992) stated:

> *“…A large portion of resources devoted to Weed Science have been devoted to herbicide research and promotion of their use. The over-emphasis on chemical weed control by many Weed Scientists will continue to retard the development of Weed Science as a balanced discipline…”* (Wyse, 1992).

Symposium on the *Biology of Weeds, 1959*

During the 1950s and 1960s, rumblings of trouble in the future were beginning to be heard (Duke, 2005). *Weed Science*, as a discipline, was heavily criticized as being a conduit for herbicide companies to market their products as they expanded.

Although the focus slowly changed to capture studies in weed biology, ecology, and non-herbicidal weed control methods, the negative perception that *Weed Science* was a discipline that was and remains focused on herbicides. Read any weed science journal - The dominant focus remains herbicides

Ideas and thoughts about '*know your enemy before you go to war*' and the need to better appreciate the biology and ecology of weeds came around that time. The need to '*know*' weeds better was of such importance that John Harper organized a symposium on the subject in 1959, under the auspices of the British Ecological Society at Oxford, April 2-4, 1959.

In the introduction to the symposium publication - *The Biology of Weeds* (Harper, 1960), he wrote that for many years, weeds had been regarded as inappropriate material for biological studies. Almost all of the weed biology studies, except for those causally related to weed control, had been severely neglected. Part of the problem why weeds were 'untouchables' among plants was the idea that the 'pure' botanist must be concerned only with 'natural' vegetation.

The standard view at that time was that these '*camp followers of cultivation'*, are the domain of Applied Botanists. Even as early as in the 1950s, only a decade after the first commercialization of 2,4-D (2,4-dichloro-phenoxy acetic acid), alarm bells were ringing loudly on its overuse. Harper warned that herbicide use was so widespread in Britain, Europe, and the USA that it ran the risk of potentially hijacking an emerging science. Introducing the 1959 symposium, he wrote, as follows:

> *"…this symposium has been concerned with the biology of weeds, which has been interpreted to exclude chemical control. This has been a deliberate policy, because symposia and conferences in weed control have been held in abundance. Herbicides are so widespread in use that they are beginning to form part of the 'normal' environment of weed populations.*
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> *"...Already weed strains have been selected, which are resistant to some of the chemical herbicides. It will be a tragedy if the botanist does not take opportunities now offered to follow the influences of this most potent force on the distribution, frequency, evolution, and dynamics of weed populations…"*

The 1959 symposium turned the attention of weed researchers to focus on the taxonomy, biology, and ecology of weeds, including their reproductive systems, origins, habitat preferences, and evolution. It encouraged s the study of weed species from an individual perspective (autecology), and as part of plant communities (synecology).

Emphasizing the environmental harm that can result from the excessive use of herbicides, John Harper steered the directions weed research should take at this crucial meeting. This move was pivotal in the development of the discipline over the next 60 years. The scientific community listened because of the esteem with which Professor Harper was held. Three years earlier, Harper (1956; 1957) had prophetically warned of the likelihood of developing herbicide resistance in weeds.

History will record this 1959 symposium at Oxford as the first real attempt to broaden the framework for studying and understanding weeds, dissociating the subject from herbicide-dominated thinking.

Promoting ecology and biology, it paved the way for *Weed Science* to develop with confidence, as an important, multi-disciplinary science. Deliberations covered how weed management research is linked with other applied crop protection research, such as Plant Pathology and Entomology and also, the importance of population dynamics and taxonomy.

The attention of the gathering was also firmly on in-depth analyses of biological attributes that make species become weeds. There was emphasis on the quantitation of negative effects of a dominant, individual weed species, their populations, or mixtures of different species (communities), in food crops, or in other production systems (such as grazing and forestry), and on water resources.

The Symposium on the *Genetics of Colonizing Species, 1964*

A much more influential symposium – the *First International Union of Biological Sciences Symposia on General Biology* – was subsequently held in Asilomar, California, during 12-16 February 1964. The proceedings – *Genetics of Colonizing Species* - Edited by George Baker and Ledyard Stebbins, published in the following year (1965) must be

regarded as the seminal landmark event in the evolution of *Weed Science*. The publication is recognized as one of the most widely read books in ecology and genetics (Barrett, 2001).

This is especially because it is at this symposium that several evolutionary biologists, such as Richard Lewontin and Ernst Mayr, made important contributions to the field of *Weed Science*, which, at that time, was struggling to find a firm scientific footing. I quote two examples below.

> *"…What would the ideal colonizer look like? That is pretty obvious; they would have effective dispersal mechanisms, high somatic plasticity, high inter-specific competitive ability; and the greatest degree of all three is most desirable…'* Lewontin (1965).

Lewontin, a Professor of Evolutionary Biology, answered the question, way back in 1965, at the Symposium, explaining what a good colonizer is. A crucial aspect of a good colonizer is the inherent, genetic variability available within the species and then, expressed in its population.

This variability in the genetic make-up, available within a population, rather than just in an individual, is what allows the species to respond well to variations in stressful environmental conditions they face during a colonization process. Different 'stress-tolerant' genes in the population get activated as a response to different environmental cues.

Their symposium deliberations shone a spotlight on how Darwin's theory of evolution via natural selection might be operating in Nature. As the Editors (Baker and Stebbins, 1965) stated:

> *"…the Symposium had as its object, the bringing together of geneticists, ecologists, taxonomists and scientists working in some of the more applied phases of ecology –such as wildlife conservation, weed control, and biological control of insect pests..."*

The explanation of possible genetic systems operating within 'colonizing species' brought the discourses within the discipline of *Weed Science* to a higher plateau than previous. Summarizing the famous 1964 symposium, Ernst Mayr, a renowned vertebrate zoologist, from Harvard, stated as follows:

> *"…Except for a few endemics, every species is a colonizer, because it would not have the range it has, if it had not spread there by range expansion, or 'colonization', from its place of origin..."* Ernst Mayr (1965)

Mayr's quote has gone mostly unnoticed in the history of *Weed Science*. However, it is significant as he highlights the similarities of 'weedy' pioneering plant species and other successful colonizers, such as house flies and rodents, and we humans.

All of the widespread species in the world have strong adaptations for range expansion. No species would be successful, from evolutionary or ecological viewpoints, *if they did not have some capability for range expansion from its place of origin*. Put simply, successful species need to have the biological attributes required and the capacity to colonize other suitable habitats.

Triumph after that depends on other factors that influence its reproductive success (inherent traits) and perpetuation of genes in the new environments through breeding and production of offspring.

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With a focus squarely on *Plant Science*, the symposium stimulated discussions on research on using weeds as model, experimental organisms to understand how plant populations behave over the next two decades. This emphasis, combined with studies on the biology, ecology and eco-physiology of individual weed species changed the direction of *Weed Scienc*e forever, which, up to that time, had an inordinately unbalanced focus on herbicides [1].

Concurrently, during this period of *ecological enlightenment*, the heightened awareness obtained on plant and animal population biology and ecological perspectives on weeds (i.e., related to succession, vacant niches, see Baker, 1965), brought in more 'science' to the *Weed Science* discipline.

By the early 1960s, other societies of biologists, especially, plant ecologists and taxonomists, influenced the directions of weed research significantly, across the globe. This brought about a change of focus of *Weed Science* from herbicides on to studies of weeds, as biological organisms, as well as correctly identifying individual species and their strengths and weaknesses (i.e., 'know your enemy before entering the battle').

[1] Robert Zimdahl offered a slightly different opinion (*personal communications*, Dec 2020) on the influence of the 1965 Symposium. While agreeing that Ernst Mayr's quote has hardly been quoted in the corpus of *Weed Science* literature, in his view, the symposium certainly stimulated discussions, perhaps more in the plant science world, but not necessarily, sufficiently, in the *Weed Science* world.

Stimulating the discourse on converting ecological theory into practical management of plant and animal populations, the *British Ecological Society* launched the *Journal of Applied Ecology*, in the heady days in the early 1960s. Launching the Journal in 1964, its first editors – Arthur Hugh Bunting and V. C. Wynne-Edwards - optimistically wrote as follows (see Ormerod and Watkinson (2000):

> *"…Ours is an age in which ecological thinking and methods can, more than ever before, contribute to the progress of mankind…'* (1964), Journal of Applied Ecology, 1, pp. 1-2.

Reviewing the literature, I find that the turnaround of focus to *understand weeds*, as purely a group of plants with special attributes for colonizing vacant niches, created by disturbances, was achieved in the late-1950s to mid-1960s period.

It is abundantly clear that the need to *understand weeds, as a basis for their control* was promoted by our founding fathers, at that time. They were also concerned about the potential for any 'new' technology, particularly, herbicide technology, to go wrong when it is used without an appreciation of unintended consequences and collateral damage.

Rachel Carson's *Silent Spring, 1962*

Apart from the *Genetics of Colonizing Spe*cies, we may also add Rachel Carson's major contribution, *Silent Spring*, published on 27 September 1962 (Carson, 1962) as a landmark, which influenced the development of *Weed Science*.

The book sounded an ominous warning to the scientific community and the public on the adverse effects of excessive pesticide use across USA. While the book's focus was largely on the persistent, organo-chlorine insecticides, such as DDT and its cousins (i.e., aldrin, dieldrin), Carson did touch on the potential negative effects of the large-scale use of herbicides as well.

The impact of *Silent Spring*, acknowledged as one of the most important and influential treatise of the 20th Century [2], was a vastly increased regulatory control of all pesticides, and the mandatory requirements of comprehensive research data on modes of action, efficacy, toxicology, and environmental fate of xenobiotics. The stringent approval requirements increased the research efforts on all pesticide applications. The additional costs for herbicide/pesticide evaluations slowed down new discoveries considerably.

On the positive side, the mandatory requirements for registration resulted in increased funding, which promoted closer working relationships between researchers, the pesticide and herbicide Industry, independent reviews, and efficacy evaluations.

In Zimdahl's view (*personal communications*, Dec 2020), the primary result of Rachel Carson's book was a steady and uniform desire among weed scientists, and especially the herbicide industry in the USA, to deny the legitimacy and correctness of her book. Many weed scientists dismissed her comments because she was, after all, only a botanist. According to at least a few detractors, she did not know any thing about weeds, or herbicides, and hence, her views did not apply to weed control with herbicides.

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With the recognition of the need to anchor *Weed Science* in its basic sciences – *Botany* and *Ecology*, over the next two decades, the emphasis shifted from herbicides to a more holistic approach to control and manage weeds. In many ways, in much the same way that dust storms in the 1930s galvanised action on the 'dust bowls' in the USA [3], a greater awareness of the problematic issue, raised with scientific data and information, spurred people on to find appropriate solutions. This change of focus led to the development of the now well-known Integrated Weed Management (IWM) approach (Thill *et al.*, 1991; Wyse, 1992; Zimdahl, 2012) and its wide-scale adoption, especially in the USA.

[2] (1) Griswold, E. New York Times (21 Sep 2012). How 'Silent Spring' Ignited the Environmental Movement (**https://www.nytimes.com/2012/09/23/magazine/how-silent-spring-ignited-the-environmental-movement.html**); (2) The *Discover Magazine* (8 Dec, 2006) listed *Silent Spring* as No. 16 of the 25 greatest science books of all time (**https://www.discovermagazine.com/the-sciences/25-greatest-science-books-of-all-time**).

[3] (1) 'Dust Bowls' is a term given to drought-stricken ~~southern plains~~ prairie states of the USA, particularly Oklahoma, which suffered severe *dust storms* during a dry period in the 1930s. As high winds and choking *dust* swept the region from Texas to Nebraska, people and livestock were killed and crops failed across the entire region, further aggravating the effects of the Great Depression (**https://en.wikipedia.org/wiki/Dust_Bowl**); (2) Fiona Harvey, 19 May 2020, The Guardian. Dust Bowl Conditions of 1930s US Now more than twice as likely to reoccur (**https://www.theguardian.com/environment/2020/may/18/us-dust-bowl-conditions-likely-to-reoccur-great-plains**).

Public concerns on the potential impacts of widespread pesticide use had also driven the science of managing insect pests towards integrated pest management (IPM) at that time. Following in the same direction, IWM was an effort to:

> *"…overcome the paralysis of the pesticide paradigm and conceive a Weed Science research program that addresses both society's perceptions of safety and the scientific community's perceptions of risks…"*
>
> Zimdahl (2012)

The discourses at that time responded to public pressure, and included scientific ideas on population and community ecology, the genetic basis of evolution, carrying capacity of ecosystems, limiting resources and limits of growth.

Arguments for reducing the large loads of herbicide and other pesticides used in agriculture swirled around in the 1960s and 1970s. A primary motivation was to achieve acceptable levels of environmental safety, while mitigating the negative economic impacts of weeds and pests with chemicals.

Whilst herbicide research continued on aspects, such as new discoveries, efficacy studies, reducing herbicide contamination of surface and ground water resources, and modifying application technology to increase weed control efficiency, IWM stimulated research and practical applications, incorporating all of the available weed control methods, based on ecological principles, weed thresholds, as well as economic goals of weed control (Thill, et al., 1991).

IWM also shifted the emphasis from 'weed control' to 'weed management', with the incorporation of knowledge of population biology (e.g., weed seed population dynamics; soil seed bank; species shifts over time) into control programmes. Aspects that our founders pushed for in the early 1960s.

Other vital elements in IWM included crop hygiene (preventative weed control); cultural practices (i.e., crop rotations, multiple cropping, and minimum tillage); and biological control. The primary intention of IWM was sustainable and ecological weed management, and large-scale reductions in the use of herbicides for weed control.

Conservation agriculture, with its emphasis on regenerating and retaining soil and crop health in an integrated manner, can be regarded as an off-shoot of sustainable agriculture, as well as an integration of principles of agro-ecology into IPM and IWM (Radosevich, et al., 1997; Altieri, 1999; Harker and Donovan, 2013).

However, away from agricultural fields, our knowledge about the ecological effects of colonizing species over long timeframes is quite limited. As a result, many of the claims against particular colonizing species, as the primary cause of biodiversity losses, are unsubstantiated allegations only.

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We must remember our founders for their contributions and the directions given at those seminal conferences to change course of Weed Science, as a discipline. We may also acknowledge the stimulation given by scientists, such as Rachel Carson, to look for ways reduce the overall use of pesticides and herbicides in managing pest species and thereby, lessen adverse environmental effects.

Nearly 70 years from our beginnings, *Weed Science* is now a mature science with a vast corpus of knowledge on specific, adverse effects of weeds in agricultural systems and other situations and how best to manage or mitigate such effects.

Even today, it is unfortunate that most published papers on weeds consider it an axiomatic truth that the presence of weeds, at whatever abundance, will always present a problem. This flawed thinking is what makes us fearful and ready to launch untenable offensives against the colonizing taxa.

If you were a real 'alien being', visiting the Planet Earth for the first time, looking around and perusing the literature on weeds, you would be thoroughly confused. All that this group of plants, branded as 'weeds', appear to be doing is to poison or hurt people, cause injury to livestock, reduce farmers' income, and agricultural productivity.

In some instances, they appear to, or are alleged to threaten other plant species and biodiversity and are blamed for it. The alien visitor would also hear some commentators deride colonizing taxa as some kind of '*alien invaders*' on the earth itself and 'as the second greatest threat to biodiversity' on the planet (see Chew, 2015).

It appears that weedy species cause a litany of other problems also to humankind, such as blocking waterways, prevent the growth of 'native' plant species, and reducing recreational opportunities, which are quite disturbing.

The alien visitor could be excused for being more frightened of meeting this group than an encounter with the human species!

Pioneering Thoughts

Humans have encountered pioneer species for millennia and have benefitted from them as plant resources. Until recent times, the interactions were without maligning of species. Ancient records indicate that humans have been using 'weedy' colonizing species for at least 10,000 years or more. The uses would have been primarily as edible food and sources of medicines and also as raw materials for various purposes including firewood. Weeds also featured strongly as fodder for domesticated animals in the past millennia, a practice that continues to date (see reviews by Altieri, 1999; Kim et al., 2008; Zimdahl, 2007; Chandrasena, 2008; 2014).

In those past millennia, weeds were not considered as major problem but only as an 'incidental issue' in cropping (Timmons, 1970). We also learnt to cope with them efficiently, as evident in the great successes of agricultural production.

The history of *Weed Science* documented so well elsewhere (Shaw, 1964; Timmons, 1970; Wyse, 1992; Evans, 2002; Appleby, 2005; Zimdahl, 2010a; Falck, 2010), demonstrates how the discipline helped to increase crop production and transform agriculture. This history also shows how the discipline then evolved and accumulated an impressive knowledge-base for dealing with colonizing plants, when and where they become problems.

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As I discussed (Chandrasena, 2020), since the early-1990s, the term '*Invasive Alien Species*' (IAS) has become familiar to a considerable segment of the scientific community and the public.

A significant portion of the *Weed Science* community has also adopted the IAS terminology, even though many ecologists are unconvinced about the underlying ecological concepts (Sagoff, 2002; 2009; 2019; Davis and Thompson, 2011; Davis et al., 2011; Guiaşu and Tindale, 2018). While debates about the appropriateness of the terminology still continue, the 'new' generation of weed researchers appear confused, as it is not always easy or possible to determine which species is 'native' or 'non-native' to a given region or continent.

The term '*alien*' is applied, nowadays, to both animals and plants with scant regard for what it means or why it was used by scientists of the past centuries.

One of the earliest Kew botanists who used the term '*alien*' was the British taxonomist Stephen Troyte Dunn (1868-1938) [4]. In introducing his book – *The Alien Flora of Britain* (1905), Dunn stated as follows:

> *"…The term alien is used here to designate any species which, though now spontaneous, originated in Britain through the human agency…".*
>
> *"...Now although alien plants are usually defined as above, and are frequently for that reason called "introduced plants" it is seldom possible to obtain any definite information as to the manner in which they actually arrived in the country..."*
>
> *"…The term "introduced plant", moreover, is not really distinctive, for all plants, native and otherwise, must have been originally introduced to their present habitats. In the great majority of cases botanists arrive at their conclusions as to the status of a species by a careful observation of its present circumstances in the British Isles, and also of its geographical distribution beyond them..."*
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> *"…Thus, a species which exists in perfectly wild and natural surroundings, both here and in the neighbouring parts of the world, is deemed indigenous, for there is no reason to suppose that its presence is due to any agent but natural dissemination at the time when the flora of North-West Europe originated. If, on the other hand, a species is always found to be connected with artificial surroundings, it is classed as an 'alien'..."*

The early botanists of the 18th, 19th, and 20th Centuries recognized the role of humans in moving plants across biogeographical regions but also appreciated that natural agencies also cause long-dispersal of plants. Those days, as the human population grew and interactions across continents increased through trade, empire-building, conquests and colonization, many plant species spread widely through the human agency, partly by accident and partly by deliberate introductions.

It was important for botanists to understand and communicate to each other the factors that caused the changes in the biogeographical distribution of species, the agencies (both human and natural) and causes of spread and the habitat preferred by the species, which successfully established themselves in the new environments.

[4] Stephen Dunn served as the superintendent in the Department of Botany & Forestry (1903-1910) in Hong Kong. At Kew, before Hong Kong, Dunn had worked on compiling the 2nd supplement of the *Index Kewensis* (**https://en.wikipedia.org/wiki/Stephen_Troyte_Dunn**).

The early writings, particularly of Stephen Dunn, indicate a great deal of caution in categorizing plant species in this way, as it was difficult to assign any species as a '*native*' or '*introduced alien'* plant without historical knowledge.

As Marcus Hall, an environmental historian pointed out to me recently [5], Dunn's use of the term '*alien*' so clearly in his book's title suggests that the word had been around for some decades. This book appears to have put a stamp on use of the word '*alien*' for 'introduced' species, many of which had become weeds in Britain.

According to Marcus Hall, it is difficult to pinpoint the origin of the term. Variations of the English terms - *alien species, alien flora, alien fauna*, also appear in several foreign word equivalents. Certainly, the term '*alien species'* was well accepted by the 1930s, particularly in Britain, and in the USA, there are references to '*alien grasses'* as early as the 1910s. These terms date back in concept to the 19th Century. "*exotic*" is a much older term.

The word 'alien' (Latin, "*alienus*") means belonging to another, not one's own, unfamiliar, unconnected, strange, or foreign. And when *alienate* first appeared in English as a legal term in the mid-15th Century, it meant to transfer ownership of some property over to someone else, so that it is now 'foreign' or 'unconnected' to the transferee. It is unfortunate that it was used in reference to introduced plant and animal species.

As a botanist, Dunn would have dealt with large collections of specimens that had been stored at the Kew Herbarium. Subsequently, Edward James Salisbury (1886-1978) a Professor of Botany at the University College, London, popularized the use of the term '*alien*' in his book on "*Weeds & Aliens*" (1961). Salisbury was also the Director of Kew Gardens in London during 1943-56 and had access to century-old herbarium specimens. He also had a considerable interest in weeds [6].

A book, entitled "*Weeds and Aliens*", published while the discipline of *Weed Science* was taking shape, in the early-1960s, would have had an impact. However, as I stated earlier (Chandrasena, 2019), the term was cautiously avoided by others. The term was then, and is even now, superfluous to any sensible and enlightened discourse on weeds.

Of course, those 18th Century botanists knew that they were collecting specimens of common, as well as rare species and not aliens from another planet. Their purpose was not to slander plant species, but to caution other botanists on the risks of introducing plants across the continents, particularly with the exchanges of live specimens among botanic gardens.

Likely, they were also aware of spreading plant species along with movements of livestock, fodder, people, and military equipment, at that time, as Dunn has described in some detail his book (Dunn, 1905, Introduction, pp. xiii-xvi).

It is most likely that Salisbury followed Dunn's practice and used the term '*alien*' interchangeably with the term '*introduced*'. Nowadays, some authors use the term to refer to plants becoming weedy when transferred from their native to an *alien* environment, meaning a new environment. Here, while the emphasis is on the new environment, the organism is also regrettably branded as an *alien foreigner*.

The issue of whether, or to what extent, some 'non-native' species, introduced into a new environment, could cause harmful effects in the new home, are matters that Ecology and Weed Science can help resolve. Notwithstanding this, as a long-term 'weed watcher', I can emphatically state that calling all such species 'invasive', which is a keystone in the IAS terminology, is an unwarranted distraction.

Negative connotations of the term '*alien*' alienates people from potentially beneficial plant resources. It also prevents weed researchers from engaging with colonizing species appropriately. The IAS confusion has resulted in some scientists creating long lists of species as 'undesirable aliens' in different countries, which, it is alleged with no real evidence, may pose intolerable biosecurity risks.

Many potentially invaluable taxa have been maligned as 'unwanted plants' that can cause major problems not only in agriculture but also in the general environment. Ecological evidence, such as how a species behaves in one environment, is the basis of 'weed risk assessments' (WRAs), the primary tool for 'border control' in many countries.

However, the flip side of WRAs is that they have lead to the listing of potentially invaluable species as 'undesirable invasives', when such a calling is scientifically contestable. Also, the maligning of species as 'invasives' is at least partly based on human interests, life experiences, personal perceptions, 'likes' or 'dislikes' of species, all of which are subjective judgements, which are fraught with danger (see Harlan and de Wet, 1965; de Wet, 1966).

The flawed concept of IAS was, however, boosted through the 1990s decade, by discussion in the news media and in publications of such

[5] Marcus Hall (Institute of Evolutionary Biology & Environmental Studies, University of Zurich) *personal communication,* Oct 2020.

[6] E. J. Salisbury (Source: **https://en.wikipedia.org/wiki/Edward_James_Salisbury).**

organizations as the Nature Conservancy Council in the USA, and the National Geographic Society.

The incorporation of the notion '*alien*' species threaten ecosystems and biodiversity in the *UN Convention of Biodiversity* (1992) gave authority to this claim, without much scientific evidence [7]. My view is that Article 8 (h) of the CBD could have been better worded with a more detailed explanation and scientific qualification.

Despite the constant maligning of colonizing plant species by the alarmists ('invasion biologists') with a myth that '*invasive aliens may engulf the world*', we need not fear them. The better we understand weeds as a group of colonizing pioneers, the faster we relieve ourselves of such fears and anxieties. I re-iterate, to 'live with weeds', we must understand and respect them better than we have done so far (Chandrasena, 2014; 2019).

However, one of the desirable effects of the IAS debate is that it has created a greater awareness in the public of 'weeds' and their potential negative effects, as well as positive and beneficial effects.

We must thank George Baker and other botanists, such as Asa Gray, John Harper, Arthur Hugh Bunting and Jack Harlan, for describing in fairly accurate terms what colonizing plant species are. The contributions of evolutionary biologists, such as Richard Lewontin (1965) and Ernst Mayr (1965) are also important in characterizing successful plant or animal colonizers as pioneering and highly resilient species and not 'aliens'.

A dip into this history, which placed the discipline of *Weed Science* in its foundational footing, is important, so that the new generation of weed scientists would be better equipped to deal with contentious issues related to weeds.

Asa Gray and 'Pertinacity' in weeds

Ideas about botanical characteristics and behavioural aspects of weeds 'as a group' arose in the mid-to-late 19th Century. In this regard, the contributions of the renowned American Botanist- Asa Gray (Figure 1) need to be recognized by all weed scientists [8].

Gray's article (1879), on the '*predominance and pertinacity of weeds*', probably inspired others to look for botanical attributes that characterized weeds. In the article, Gray highlighted the close relationship between weeds and human endeavours, as follows:

> *"…A weed is any plant which obtrusively occupies cultivated or dressed ground, to the exclusion or injury of some particular crop intended to be grown. Thus, even the most useful plants may become weeds if they appear out of their proper place.*

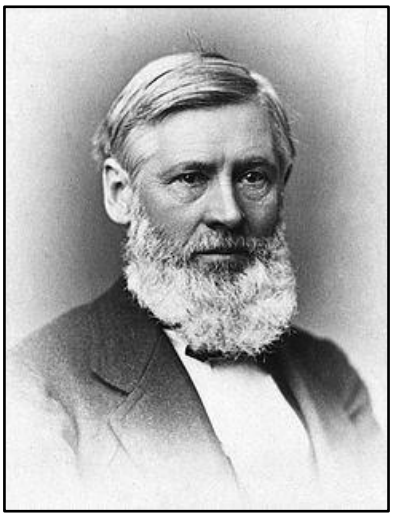

Figure 1. Asa Gray (1810-1888) (**https://en.wikipedia.org/wiki/Asa_Gray**)

> *"...The term is sometimes applied to any insignificant-looking or unprofitable plants which grow profusely in a state of nature; also, to any noxious or useless plant. This excludes predominant indigenous plants occupying ground in a state of nature. Such become weeds when they conspicuously intrude into cultivated fields, meadows, pastures, or the ground around dwellings..."*

> *"…Many are unattractive, but not a few are ornamental; many are injurious, but some are truly useful. White Clover is an instance of the latter. Bur Clover (Medicago denticulata) is in*

[7] The ***Agenda 21*** for Sustainable Development, drawn at the UN's famous *Earth Summit* (Rio Conference, held in Rio de Janeiro, Brazil, 3-14 June 1992), a 351-page document, mentions the terms - 'weeds' and 'herbicides', each, only once. However, the *Convention for Biological Diversity* (CBD), also drawn at the same Summit, gave the terminology related to '*invasive species*', its recognition (Source: **https://web.archive.org/web/20090510093432/http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm**).

[8] Asa Gray was Fisher Professor of Natural History, Harvard University, 1842–73. He wrote numerous botany textbooks and on the North American flora. He was also the President of the American Academy of Arts and Sciences (1863–73); of the American Association for the Advancement of Science (1872), Regent of the Smithsonian Institution (1874–88), and Foreign member, The Royal Society of London (1873) (Source: **https://www.encyclopedia.com/people/science-and-technology/botany-biographies/asa-gray**).

California very valuable as food for cattle and sheep, and very injurious by the damage which the burs cause to wool…"

"…In the USA, and perhaps in most parts of the world, a large majority of the weeds are introduced plants, brought into the country directly or indirectly by man. Some such as Dandelion, Yarrow, and probably the common Plantain and the common Purslane, are importations as weeds, although the species naturally occupy some part of the country..."

In my reading of history, Gray was the most eminent 19th Century botanist, who first questioned: "*Why are weeds so pertinacious, aggressive, and successful? Are their common characteristics that give weeds an advantage over others?*"

Gray used an unusual term - '*pertinacity*' to describe the attributes of weedy species, such as persistence, tenacity, and stubbornness. Although he called these specific 'weedy' attributes, such characteristics are behavioural, rather than truly botanical and heritable. Yet, he did recognize certain qualities in many weeds, which were better explained by George Baker and others in subsequent years.

The term **pertinacity** describes the quality of persistent tenaciousness, i.e., sticking with something, not giving up, no matter what. It is a type of persistent determination and is a mix of courage, conviction, and a little stubbornness.

Gray was also clear in his mind that some American weeds were immigrant species from the Old World, which originated in the 'forest-covered' regions of Europe. Naming several such species, he suggested that many such species followed 'husbandmen and flocks', and spread far and wide by sheep and cattle, as agriculture and pastoralism expanded in the continent, prior to migration to the New World via the human agency.

As far as Gray was concerned, the prevalence and dominance of both European weeds (Old World) and American weeds (New World) could be explained by the disturbances, caused by '*sudden*' land use changes and '*communication changes, such as the railroad*' that were occurring in the American continent, at that time.

Gray (1879) also highlighted the spread of both categories of weeds '*step by step, and somewhat in rapid strides'* across the USA, caused by livestock, movement of feedstock, people, and equipment associated with humans.

Writing 140 years ago, Gray also concluded that self-fertilization was not a prerequisite for plants to become aggressive and predominant weeds, whether they be European immigrants arriving in the Eastern States (of USA), or those spreading in the Western States, such as California (quote below).

"...Self-fertilization is neither the cause nor a perceptible cause of the prepotency of the European plants which are weeds in North America. A cursory examination brings us to a similar conclusion as respects the indigenous weeds of the Atlantic States, those herbs which under new conditions, have propagated most abundantly and rapidly, and competed most successfully for the possession of fields that have taken the place of forest..."

We now know that many colonizing taxa are adapted for both self-fertilization and cross-fertilization. A large number of taxa get cross-fertilized through wind (e.g., grasses) and those that produce attractive flowers, by insect visitors.

Gray's critical observations on the persistence, tenacity, and stubbornness of some weedy species, shed an early light on botanical attributes, ecological behaviour, and characteristics of weeds.

From a historical viewpoint, it is important to note Gray's writings, which also showed how weeds cross continents, and then spread following human immigration ('*weeds as shadows of men'*). He also understood and wrote about 'disturbances' and landuse changes, perhaps, the most important two key drivers, which assist weeds to be established.

George Baker and the '*Ideal Weed*'

Now I wish to revisit Dr. Herbert George Baker's characterization of the 'Ideal Weed' and discuss issues related to this enlightened understanding of colonizing species. I am motivated by the constant stream of articles that I read in the submissions received by this Journal. I am distressed that most papers appear to start with the premise that an all-out assault on weeds with herbicides is a must to increase crop production or manage our environmental assets. This highly questionable view needs to change.

In 1965, Herbert George Baker [9], from the University of California, Berkeley, provided what most weed scientists consider the most elegant ecological definition of what a weed is (Baker, 1965).

[9] H.G. Baker was a British-American botanist and evolutionary ecologist who was an authority on pollination biology and breeding systems of flowering plants. (Sources: H.G. Baker - In Memorium (**https://senate.universityofcalifornia.edu/_files/inmemoriam/html/bakerhg.htm**); and (**https://en.wikipedia.org/wiki/Herbert_G._Baker**)

"…A plant is a weed if, in any specified geographical area, its populations grow entirely or predominantly in situations disturbed by man, (without, of course, being a deliberately cultivated plant). Thus, weeds include plants which are called agrestals (they enter agricultural land), as well as those which are ruderals (and occur in waste places as well as along roadsides)…"

"…In many cases, the same species occupy both kinds of disturbed habitat. Ruderals and agrestals are faced with many similar ecological factors, and the taxa which show these distributions are in my usage, 'weedy. Such disturbed habitat is mostly, but not exclusively, associated with man's activities and are at least partially created by man…"

Figure 2. Herbert George Baker (1920-2001) (Source: https://en.wikipedia.org/wiki/Herbert_G._Baker)

Baker, then went on to produce a list of attributes (Table 1) that depicted a successful weed: an '*Ideal Weed*'. By comparing traits of 'weedy' and 'non-weedy' relatives of the same genus (called, 'congeners'), he proposed that species, which exhibit several of the traits would be significant weeds. In contrast, those that display a few of the traits would be minor weeds. Colonizing species possess some or most of these characteristics.

Baker explained that the more of these characteristics an individual species has, the 'weedier' it would be. *Fortunately, there is no single claimant weed owning all of these characteristics collectively.* Those that depend on seeds for will grow fast to reproductive maturity. They will produce large numbers of seeds, some of which live long buried in the soil. While some seeds may germinate quickly, a portion will remain dormant until conditions become favourable for germination.

At least 85 years after Asa Gray's observations, in describing '*The Ideal Weed'*, Baker recognized '*self-compatibility, but not complete autogamy or apomixy*'; and '*cross-pollination by unspecialized visitors or wind*' as major characteristics of such taxa, along with 'phenotypic plasticity' and 'environmental adaptability' (Table 1).

Baker proposed that colonization is likely to be more successful for species with an ability to self-fertilize, and thus, to establish new populations as single individuals. As a result, self-compatibility, he suggested, should be common among colonizing species.

Table 1 Baker's 'Ideal Weed' Characteristics

Category	Characteristic
Seed bank-related:	• Germination requirements fulfilled in many environments. • Discontinuous germination and great longevity of seed.
Vegetative growth-related:	• Rapid growth through vegetative phase to flowering. • If a perennial, vigorous vegetative reproduction or regeneration from fragments; • Brittlenenss, so as not to be drawn from ground easily. • Ability to compete interspecifically by special means (rosette, choking growth, allelochemicals).
Reproductive Phase:	• Continuous seed production for as long as conditions permit. • Self-compatibility, but not complete autogamy or apomixy. • Cross-pollination by unspecialized visitors or wind. • Very high seed output in favorable environments. • Production of some seed in wide range of environmental conditions; tolerance and plasticity. • Adaptations for short- and long-distance dispersal.

This idea, labelled by Stebbins in honour of Baker as '***Baker's Law***', was influential in discussions of the evolution of sexual-systems and mating-systems in species, which are successful in establishing populations through long-distance dispersal in different environments.

Baker's Law describes the benefits of self-compatible hermaphroditism in highly successful species for their establishment, following long-distance dispersal. In the 1950s and 60s decades, these ideas were important to understand not just island colonization by successful colonizers but also the constraints imposed by low-density conditions (lack of mates) on plant reproduction.

Baker was also the first to really stress life-history considerations and the importance of local environmental conditions for understanding the evolution of mating patterns in the successful colonizing plant species. In describing the characteristics of '*The Ideal Weed'* (Table 1), Baker recognized cross-fertilization by unspecialized insect visitors (such as ants) or wind-pollination, both of which are predominant in grasses (Poaceae) as important mechanisms for successful colonizers.

The effect of Baker, along with others, such as Stebbins, has been significant in Weed Science's evolution, even though the discipline has long suffered from being sucked into the vortex and belief that herbicides will solve all weed problems. Discussions on the evolution of weeds (see Baker, 1972; 1974) helped draw the emerging discipline away from herbicides into botany and ecology. The latter placed Weed Science within the realm of a broader scientific endeavour, incorporating research into plants' genetic systems and evolutionary biology.

In paying homage to these outstanding evolutionary biologists, Spencer Barrett (2001) explained that the tremendous interest in the ecology and evolution of plant reproduction during the 1980s, 90s decades is in no small way due to Baker's early influence in stimulating research in this field.

Several of Baker's reviews, such as ''Reproductive Methods as Factors in Speciation'' (Baker, 1960) and ''Evolutionary Mechanisms in Pollination Biology'' (Baker, 1963), promoted new research directions and influenced forging cross-disciplinary links between plant ecologists and those in genetics and evolutionary biology (Barrett, 2001).

Baker's list has been heavily used in weed ecology studies and is often used to predict which weeds will become more problematic in different habitat. In my view, the fundamental proposition Baker made remains the keystone of *Weed Science*, and the list is where modern teaching of the discipline should also begin. Agricultural scientists, in particular, would benefit from such a deeply biological and ecological understanding of weeds, as species, before they attempt weed control.

As John Harper explained in *The Population Biology of Plants*, in disturbed habitat, weeds can be better managed by understanding how individuals in plant populations interact with each other and the environment, and by manipulating factors that maintain their field populations (Harper, 1977).

This, however, requires knowledge of both weed biology (life cycle strategies of individual species) and ecology (interactions of a weed with both its biotic and abiotic environment, including the soil environment).

Flexibility in reproduction is common in many weeds, as the subject specialists know well. Baker himself stated that "*weeds are excellent subjects for the study of microevolution*". In any given species, genetic variations may not be present to control all of the 'weediness traits' equally.

In his contribution to *Weed Science*, Baker introduced the concept of ''general-purpose-genotype'' to refer to colonizing species that possess broad ecological tolerance to a wide range of environmental conditions but are often displaced from undisturbed communities by specialists with a high degree of local adaptation.

While confirmation of the existence of general-purpose-genotypes within plant or animal populations has remained elusive; this embryonic idea stimulated research on phenotypic plasticity and the evolution of specialist versus generalist strategies, to be successful colonizers (Barrett, 2001).

Individuals colonizing a new habitat often face the fundamental problem of a lack of mates. Baker hypothesized that species with the ability to reproduce uniparentally are more likely to successfully colonize new areas compared with species that rely on mates for propagation (Baker, 1955). While the scenario of island colonization and establishment originally influenced his thoughts, he later applied this concept to the evolution of weedy species that colonize agricultural landscapes (agrestals) and those that dominate in waste or poorly-managed areas, such as roadsides and railroad tracks (Baker, 1965).

The influence of Baker's ideas on the origins and evolution of weeds and breeding systems of colonizing species has been quite significant over the past several decades, as shown in two such weed research studies, highlighted below.

In one study, on the genetic expressions of weedy traits in common morning glory (*Ipomoea purpurea*), Chaney and Baucom (2012) found increased 'weediness' in the species to occur through

selection on the reproductive output and competitive ability, rather than through selection on growth rate. Such research shows which weedy traits are more significant in a given species in determining how it would respond to different environmental stresses.

In another study, Van Eten et al (2017) agreed with Baker's view (Baker, 1991) that weedy species were excellent models to examine the breeding systems that allow species to successfully colonize novel environments. Suggesting that '*not all weeds are created equal*', the authors examined the hypothesis that weedy plants have an increased likelihood of being self-compatible compared with 'non-weedy' plants, a hypothesis derived from the afore-mentioned Baker's Law.

The study used an analysis of a combined database of the weedy-status (weedy or non-weedy) and introduction-status (introduced or native) of plant species found in the USA with a database of plant sexual systems, to determine whether native and introduced weeds varied in their sexual systems compared with native and introduced non-weeds.

The results showed that introduced weeds were overrepresented by species with both male and female functions present within a single flower (hermaphrodites) whereas weeds native to the USA were overrepresented by species with male and female flowers present on a single plant (monoecious species). Overall, the results supported Baker's Law at the level of the sexual system, thus providing further evidence that uni-parental reproduction is an important component of being either a native American or introduced weed from overseas.

As Baker suggested, species that reproduced uniparentally were more likely to successfully establish in a new habitat, where, initially, mates may be lacking for reproduction (cross-fertilization).

Conclusions

A primary intent of this Editorial is to encourage weed scientist and weed managers, across continents, to think differently about weeds.

The collective wisdom of all weed scientists and other specialists, such as social scientists and those who specialize in ethnobotany appear important in this regard. We must aspire to bring about a change in farmers' mind set, as well as an attitude change among landholders and governments.

Relaxing the attitude towards colonizing species will come with time, but this can be hastened by economic incentives to manage weeds as part of the biodiversity within individual farmlands and vast farming landscapes, rural areas, or countryside. The recognition of biodiversity values of weeds and the tolerance of beneficial weeds in arable weeds has been recommended in Western European countries, including the UK (see discussions in Chandrasena, 2008; 2014).

I contend that revisiting the attributes of successful colonizers, as our founders did, would make us better understand weeds. Attention should focus on the processes by which weedy taxa 'colonize' new habitat.

If one understood the factors that determine the outcome - success or failure of those colonization attempts - that would undoubtedly be helpful in how we may respond to an undesirable colonization event, or perhaps, enhance our response to desirable colonization.

Baker, in his last decades of life did not get involved in the controversy created by the 'invasion biologists. Barrett (2001), who knew Baker well, wrote that Baker was one of the least judgmental people he had ever met as the latter rarely took a public stand on controversial issues. However, I have no doubt, that in discussing the breeding systems, pollination and evolution of weedy species, Baker avoided the use of the term 'invasion'. His preference was to use the more ecologically correct term 'colonization', which is a component of plant succession.

The resilience of weeds, their tenacity, and the capacity to adapt to environmental disturbances need to be recognized not just as harmful but also as potentially beneficial. It is clear that *the very success of these plant taxa in the environment is also their weakness.* Their verdant growth, abundance, and persistence, in some situations, is what brings them into conflicts with human objectives.

Perhaps, a deeper ecological understanding would help modify our attitudes allowing us to avoid conflicts with potentially useful colonizing plant taxa and getting into situations from which we cannot win.

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A critical issue for *Weed Science* is the persistent slandering of colonizing plants as 'invasives' by some. Such disparaging inhibits studying them and appreciating their redeeming values and thereby welcoming them into our lives and environment. The prevailing negative perception that all weeds are bad, under all circumstances, needs to change. Addressing this anomaly requires recognition of the beneficial effects and values of colonizing plants, as part of the Earth's rich bio-diversity.

Shifting the emphasis of weeds from '*foe' to friend*' requires vigorous campaigning by enlightened weed scientists and ecologists, working within or

outside *Weed Science*. Presently, positive engagement with weedy species is championed only by popular websites and patrons of sustainable lifestyles and herbal medicine who are outside the *Weed Science* community.

There is also a question we must content with – *who would pay for long-term studies on the beneficial effects of colonizing species?* As the history of *Weed Science* shows, only chemical companies were willing to fund applied weed research, because of the profits they could derive from herbicides. Despite the alarming rise of herbicide-resistant weeds, across continents (Heap, 2020), funding for herbicide research continues unabated even today.

There is no simple remedy for weed problems in their many manifestations. Therefore, we need to continue our studies on the best management strategies and control tactics to manage their negative effects. Thanks to contributions from founders, such as Asa Gray and George Baker, *Weed Science* does understand quite well the reasons why colonizing species come to dominate landscapes. We also know a great deal about how to manage them.

Weed management approaches need to be designed to prevent the introduction of potentially problematic colonizing taxa to new habitats and to provide rapid responses to minimize undesirable effects where conflicts arise between man and colonizing species.

Alternatively, we must come to an accommodation that such an introduced species, may, perhaps, establish successfully and expand its territory, producing a variety of effects, some of which could be at least temporarily undesirable from a human point of view. It is my view that nearly all other plant and animal species will accommodate the 'foreigner' because that is how Nature responds.

I believe that management of colonizing species should be done best with a deep and proper ecological understanding of such species. Management should also be undertaken with a balanced view of economic, environmental, and social implications, but without dramatizing weed issues, and certainly avoiding messages that create a visceral dislike for the colonizing plant taxa.

As I have discussed in this Editorial, our founders were emphatic in explaining that weeds are botanically only 'colonizing plants', and their management will be best undertaken within an ecological framework. Wherever or whenever man disturbs a habitat, they will be among the first *pioneers* to make use of the opportunity of space ('pioneers of secondary succession', *sensu lato*, Bunting, 1960).

Downplaying this ecological emphasis, because of a focus on herbicide-based weed control, is disingenuous. In natural or man-made ecosystems, many weeds serve valuable ecological functions that need more recognition. Examples of their complex biological role, such as providing resources for wildlife, pollinating insects, slowing erosion, building soil, and generally enriching biological diversity, are abundant in global literature; these need to be studied more and given more extensive publicity.

In a strategic approach to managing weeds, more people – weed scientists and students – should explore different ways of using these taxa for improving not just the environment but also the 'human condition'.

A key to sustainable living is to *learn from weeds* to be more resourceful and *not ask for more*. If all men become thrifty, and asked for less, we could reduce our environmental impacts, both as individuals and as societies. Such a change would make our Earth a much safer place for all species.

Negative assumptions on weeds, formed over about two centuries in the field of agriculture, have inhibited ecologically-oriented weed research in areas outside agriculture. Such inhibitions need to be removed in the future to bring about a balance in the scientific discourses and messages to the public.

To end this Editorial, I would reiterate that insights about how our founders "saw" colonizing species are critically important for the next generation of weed scientists. As I said previously (Chandrasena, 2019), quoting Marcel Proust, '*without history man is nothing*'. Through a study of man's historical relationships with weeds, the next generation of weed scientists must realize that *weedy species are no more villainous than man himself*.

With or without the presence of humans on the planet, colonizing species will play vital roles in stabilizing the earth's damaged ecosystems. They will also survive any catastrophe on the earth much better than humans would.

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